Bistatic GPR by using an optical electric field sensor

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Abstract— **In order to apply to land mine detection effectively, bistatic GPR using an optical electric field sensor as a receiver has been developed. The optical electric field sensor is very small and uses optical fiber instead of metallic coaxial cable. With the combination of these advantages and the bistatic radar system, it can be possible for an operator to measure quite flexible and safely. The sensor has been tested in stepped frequency radar system with frequency which consists of a vector network analyzer, a fixed double ridged horn antenna as transmitter and computer controlled receiver-positioner for 2D scanning. For considering effectiveness in real field, we applied impulse radar system, which consist of a digital oscilloscope and a impulse generator to produce the impulse with 250 *psec* pulse width and the diffraction stacking has been adopted for 3D image reconstruction. Detection of a PMN2 mine model was carried out by the impulse radar system at a sand pit with two modes of data acquisition: the stepped data acquisition and the continuous data acquisition. The PMN2 were detected clearly with sufficiently high resolution in TM mode measurement in both modes, the target contrast was almost the same while the scanning time decreased down to 1/18, 9 min/m² in case of continuous data acquisition mode which satisfies the requirement for practical use.**

Keywords-component: Bistatic GPR, Optical electric field sensor, stepped frequecy radar, impulse radar

I. INTRODUCTION

Ground Penetrating Radar (GPR) is a method for exploring near surface geological structures, subsurface objects, ground water using a high frequency electromagnetic wave[1]. And an application of GPR to demining has begun, on demining by GPR, conventional GPR has a some disadvantage which is the size of the antenna: sometimes the size of an antenna is too large and heavy to carry and scan over the ground surface safely and smoothly. Only slight pressure may trigger the explosion of mines, if the antenna touches the ground. Therefore the antenna must keep clearance toward the ground surface. This means that the smaller and lighter the antenna is, the safer and more convenience land mine detection becomes.

An optical electric field sensor is a passive sensor which modulates the optical signal strength by the electric field[2]. The sensor is made of nonmetallic materials except the electrode, and the size of the sensor is small and light comparing to a conventional metal-based antenna. And it does not need a metallic coaxial cable and batteries, therefore it has been applied to a borehole radar measurement[3]. In our laboratory, a bistatic radar system using a optical electric field sensor has been developed, which is based on stepped frequency radar system[4]. Although its ability to detect buried objects such as land mine has been clarified, it takes very plenty of data acquisition time. For considering effectiveness in real field, we apply impulse radar system which consists of a digital oscilloscope and a impulse generator to produce the impulse with 250 *psec* pulse width. The detection of a PMN2 landmine model is carried out by the impulse radar system at a sand pit, which provides a more realistic condition and the data by two modes, the stepped data acquisition and the continuous data acquisition, are compared.

II. OPTICAL ELECTRIC FIELD SENSOR FOR GPR

Figure 1 shows the structure of the optical electric field sensor. Light with a uniform wavelength and amplitude is input into an optical wave guide embedded in a *LiNbO₃* board. Then, the electric field fed through the connected antennas is applied to the wave guides and induces the optical phase shift between two optical paths by the electro-optic effect. This phase shift causes interference at the optical output path and varies the optical intensity. This modulated light is transformed into the electric field by a photo diode, and then converted into a RF signal as output.

The optical electric field sensor has several advantages. Firstly, because it modulates the optical signal strength by the electric field strength, the sensor does not need a metal coaxial cable, which disturbs the electric field. Secondly, the sensor itself is consisted of nonmetallic parts except electrode and antenna element. Thus little disturbance toward
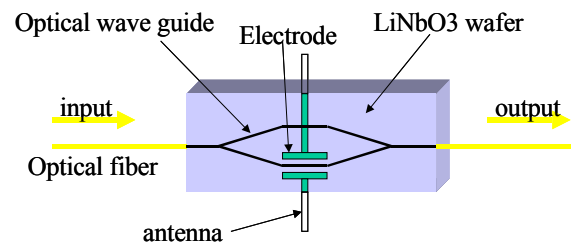

Figure 1. Construction of the optical electric field sensor.

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electric field is expected. Thirdly, the size of the sensor is very small (1cm x 7cm), so it is easier to control and scan in a narrow space or near the ground surface.

III. STEPPED FREQUENCY RADAR VS IMPULSE RADRA

In our bistatic radar systems, the transmitter is fixed at a certain position and the optical electric field sensor as a receiver scans over the ground surface where an object is set. Figure 2 shows the measurement system diagram of stepped frequency radar. A vector network analyzer (HP8720ES) transmits a frequency domain signal through a coaxial cable to a double-ridged horn antenna that is especially effective for generating high electromagnetic fields with relatively low input power. The optical electric field sensor is mounted on a scanning beam supported by a x-y stage which is capable to move two dimensionally up to 1 m by 1 m square. A position controller controls this x-y stage. The entire data acquisition system is controlled by a PC connected with the vector network analyzer and the position controller through GPIB interface
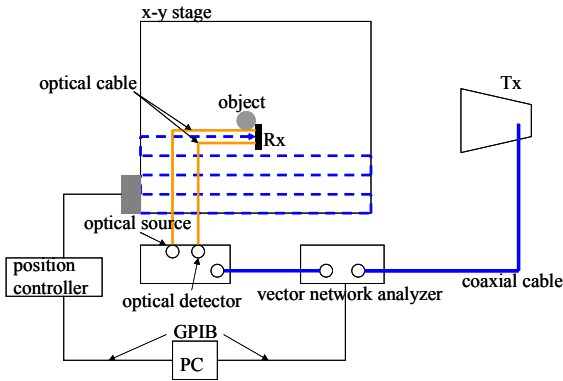

Figure 2. The measurement system diagram of the stepped frequency radar system.

The stepped frequency radar system needs long time to acquire data although it has high S/N ratio. For practicability, we have considered an application of an impulse radar system to the bistatic radar system. Figure 3 shows the measurement system diagram of the impulse radar system. The vector network analyzer is replaced with a combination of a digital storage oscilloscope (Infiniium 54855A) of which sampling frequency is 20 GHz and a pulse generator.

The pulse generator transmits an impulse of which pulse width is 250 *psec* to the transmitter, and transmits a trigger signal to the digital storage oscilloscope. Other equipments are the same as the stepped frequency radar system. We applied a high pass filter of which cut off frequency is 25 MHz in order to remove consistent noise due to the laser diode oscillation of the optical system.

By replacing the stepped frequency radar system into the impulse radar system, the transfer function of the radar system changes. In order to understand the difference of the signal characteristics between the stepped frequency radar system and the impulse radar system, we acquired a transmission between a transmitter and the optical electric field sensor for both radar
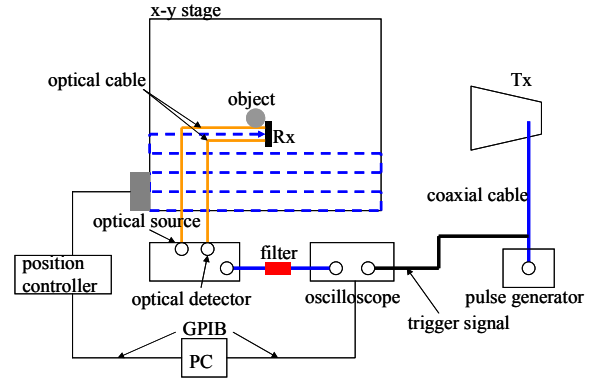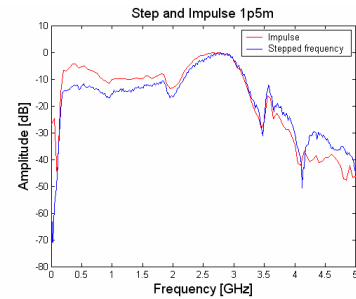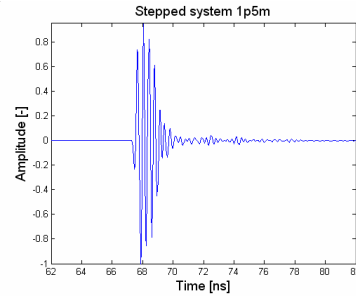

Figure 3. The measurement system diagram of the impulse radar system.
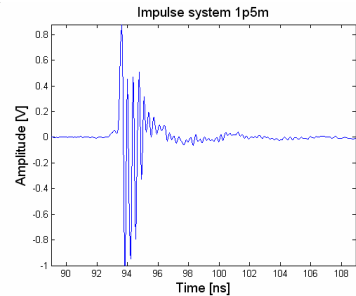
systems. The transmitter was a double ridged horn antenna and set 1.5 m away from the sensor. Figure 4 shows measured transmission which we obtained.

(a) Frequency domain signal by the stepped frequency radar system and the impulse radar system.

(b) Time domain signal by the stepped frequency radar system.

(c) Time domain signal by the impulse radar system.

Figure 4. Measured transmission between the double ridged horn antenna and the optical electric field sensor at a distance of 1.5 m.

In Figure 4 (a), we find that the frequency characteristic of each signal has a similar shape within the effective bandwidth. Figure 4 (b) shows the time-domain transmission by the stepped frequency radar system and Figure 4 (c) shows that by the impulse radar system. In Figure 4 both signals are normalized by each maximum absolute value for comparison. We find that the signal resolution, duration and the S/N level are almost the same. Therefore we conclude that both signals have a similar quality. Also data acquisition time of impulse radar system was more than 8 times faster than one of stepped frequency radar in case of the stepped data acquisition mode. After this, we focused on the results by impulse radar system.

IV. STEPPED AND CONTINUOUS DATA ACQUISITION

The stepped data acquisition means that the optical electric field sensor as the receiver acquires data as it stops at each data acquisition position. Therefore the receiver dose not move continuously but it steps. If the receiver moves continuously, the radar system approaches a practical application in a sense of scanning time. In the continuous data acquisition, the receiver acquires B-scan data sets while moving and stops only to turn at the edge of a scanning area. All the measurements were conducted by the impulse radar system by both the stepped data acquisition and the continuous data acquisition

The experiments for detecting landmine were conducted on the sand pit. The dimensions of sand pit are 4 m x 4 m with 1 m depth and sand is put 50 cm in depth, therefore it provides a more realistic condition for the measurement and a large x-y stage is installed on the sand pit and it is controlled with 1 mm accuracy.

Figure 5 shows the measurement configuration. The origin of the spatial x-y-z coordinate was defined at the point right above object on the ground surface. The radar target (PMN2 landmine) was buried at a depth of 5 cm in sand. The feeding point of the transmitter was set at (x: 238 cm, y: 0 cm, z: 111 cm). The receiver scanned an area of 102 cm by 100 cm. The
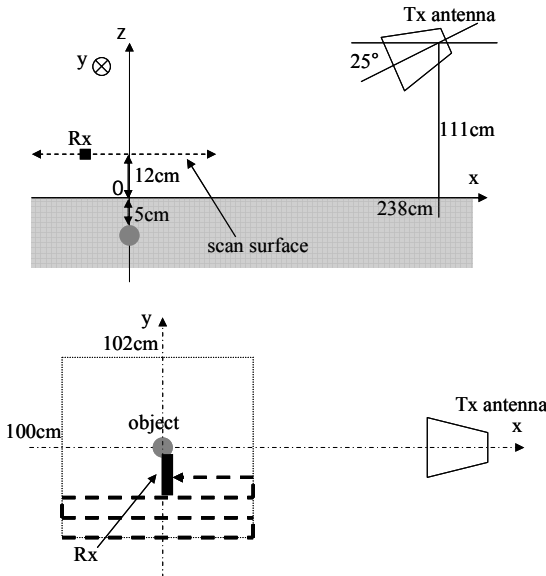
increment of the acquisition in the x- and y-direction was 1 cm. The height of the scanning surface was 12.5 cm. The ground surface was beaten and flattened. The relative dielectric constant was measured by TDR as 4.82.

We applied two kinds of electric field incident polarizations: horizontal (TE mode) and vertical (TM mode). We inclined the transmitter at an approximately 25 degrees, which was estimated from the reflection coefficient of TM mode polarization downward the ground surface to take the advantage of the Brewster angle effect.

The signal processing flow chart is shown in Figure 6. The signal processing flow is common both in the stepped and the continuous data acquisition. The acquired time domain data is transformed into a frequency domain data by Fourier transformation. We applied Wiener inverse filter for pulse compression. Then the data is returned to a time domain data by inverse Fourier transformation. Using the time domain data, we applied the Diffraction stacking and obtained reconstructed images of the target[4].
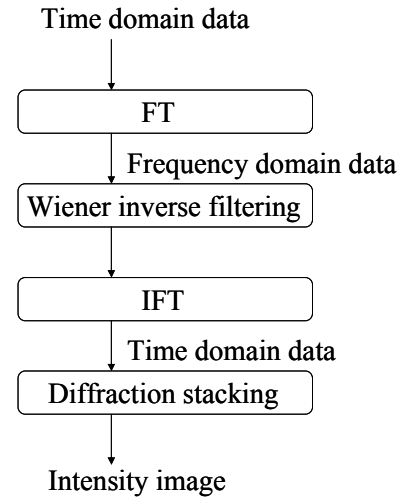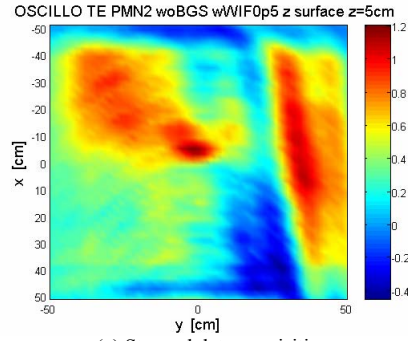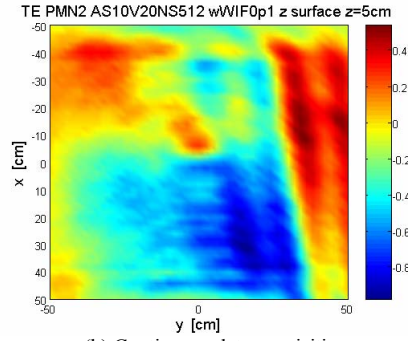
Figure 6. Signal processing flow chart.

Figure 7 (a) shows the reconstructed image of the PMN2 by TE mode by the stepped data acquisition and Figure 7 (b) shows the reconstructed image by the continuous data acquisition when the acquisition increment is 10 mm and the receiver velocity is 20 mm/s. In the continuous data acquisition, the target contrast is low and we can hardly find the reaction of the PMN2 in Figure 7 (b).

Figure 8 (a) shows the reconstructed image of the PMN2 by TM mode by the stepped data acquisition as a reference, and Figure 8 (b) shows the reconstructed image by the continuous data acquisition when the acquisition increment is 40 mm and the receiver velocity is 60 mm/s: the scanning velocity is the fastest one. Comparing Figure 8 (a) to Figure 8 (b), the target contrast by the continuous data acquisition is kept well. Comparing the resultant image by stepped data acquisition to that by the continuous data acquisition, the target contrast almost the same while the scanning time decreased down to 1/18, 9 min/m².
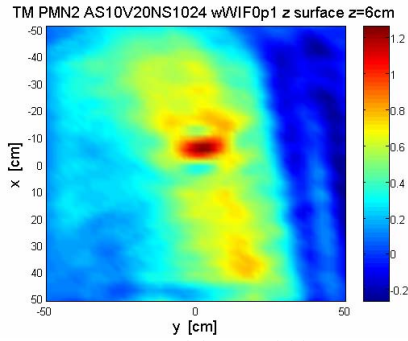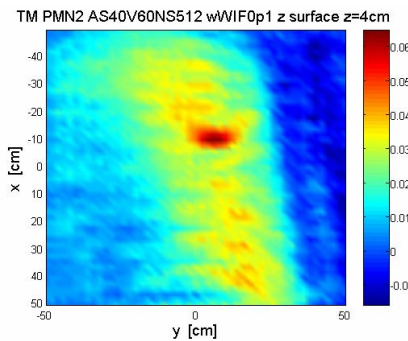
Figure. 5. The measurement configuration. (upper: the side view , lower: the top view)

OSCILLO TE PMN2 woBGS wWIF0p5 z surface z=5cm

(a) Stepped data acquisition.

TE PMN2 AS10V20NS512 wWIF0p1 z surface z=5cm

(b) Continuous data acquisition

.Figure 7. The reconstructed images of the PMN2 buried in sand by TE mode.

TM PMN2 AS10V20NS1024 wWIF0p1 z surface z=6cm

(a) Stepped data acquisition.

TM PMN2 AS40V60NS512 wWIF0p1 z surface z=4cm

(b) Continuous data acquisition

.Figure 8. The reconstructed images of the PMN2 buried in sand by TM mode.

V. CONCLUSION

We constructed the bistatic radar system based on the stepped frequency radar system. Then we replaced the stepped frequency radar system with the impulse radar system, of which data acquisition is much faster, and compared them in terms of the signal characteristics, and we found that both signals have a similar quality. The data acquisition time of impulse radar system was more than 8 times faster than one of stepped frequency radar in case of the stepped data acquisition.

We carried out detection of a PMN2 landmine model by the impulse radar system at a sand pit, which provides a more realistic condition. Data acquisition was implemented by two modes: the stepped data acquisition and the continuous data acquisition. Both in the stepped data acquisition and the continuous data acquisition, the PMN2 were detected clearly with sufficiently high resolution in TM mode measurement. Especially in the continuous data acquisition, the fastest receiver scanning velocity was estimated. And we found that while the scanning time reduced to 9 min/m^2, the quality of the resultant image remained almost the same. In addition 9 min/m^2 satisfies the requirement for practical use.

In this study, detection of buried objects was carried out with a relatively ideal condition: the ground surface was flat, the subsurface medium was homogeneous and the radar target was relatively large. Therefore further estimation of the system with more realistic condition is necessary for practical application.

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